TECHNICAL REPORT NO. 9689 (LL 115)

ANALYSIS OF
ESTIMATED RIVER EXITING PERFORMANCE

July 1967

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Land Locomotion Division

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COMPONENTS RESEARCH & DEVELOPMENT LABORATORIES
U.S. ARMY TANK AUTOMOTIVE CENTER WARREN, MICHIGAN

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ABSTRACT

A previous study of river magnitude and frequency established river exiting as the primary problem for vehicles attempting to cross rivers. Analysis of the exiting problem indicated that the single most important parameter to be considered was the geometric form of the river bank. Evaluation of the probability of an M-113 exiting at each bank surveyed in the magnitude and frequency study was made by relating vehicle performance characteristics to bank descriptions; a determination of the probability of the vehicle exiting was then made on a GO or NO-GO basis. Since much of the environment was extremely severe with respect to M-113 capabilities, this evaluation was fairly straight forward. A numerical method, using a geometric severity to classify bank geometry, was then developed to permit a performance analysis to be conducted on a rational basis.

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FOREWORD

A previous study of river magnitude and frequency established river exiting as the primary problem to vehicles attempting to cross rivers (Ref. 1). * Sufficient information was collected in that study to permit analysis of the exiting problem. The first portion of the analysis identified the exiting difficulty as caused primarily by the geometric form of the river bank. The probability of an M-113 exiting at each bank was then estimated by relating M-113 performance characteristics to the bank description and determination of the probability of the vehicle exiting was made on a GO or NO-GO basis. Following this analysis a second, numerical method was developed. This method used a geometric severity factor to classify bank geometry, and allowed the performance analysis to be conducted on a rational basis.

Findings

The qualitative analysis of 226 banks studied in the eastern portion of the country showed that:

Negotiable by a M-113	27 percent
Obstacle due to slope greater than 50 percent	35 percent
Obstacle due to vertical wall greater than 3 feet	23 percent
Trees would prevent exiting	8 percent
Marsh or swamp would prevent exiting	7 percent

A geometric severity factor, developed to classify river bank geometry, was found to correlate well with the qualitative performance analysis and with the limited test data available from the Swamp Fox II Exercise (Ref. 2).

An analysis, using the geometric severity factor to predict vehicle performance, indicated that on the banks surveyed an M-113 would:

negotiate the bank	28 percent
have marginal success	17 percent
not negotiate the bank	55 percent

* Numbers indicate references listed at the end of this report.

An analysis of the banks surveyed on the Black and Huron rivers in Michigan, using the geometric severity factor, showed:

negotiate the bank	58 percent
have marginal success	19 percent
not negotiate the bank	23 percent

Approximately 80 percent of the river banks surveyed had a geometric severity which indicated that they were not insurmountable from a purely geometrical standpoint if an adequate exiting aid were developed.

Conclusions

1. The primary reason for vehicle difficulty in exiting from a river is the geometrical severity of the bank slope.

2. A simple classification scheme can be used to relate vehicle exiting performance to river bank geometry.

3. The fact that 68 percent of bank heights are less than 12 feet and 80 percent of the geometric severity factors are less than 10 feet, indicates that the use of an adequate exiting aid would allow a M-113 type vehicle to exit on approximately 80 percent of the banks encountered in the Eastern United States.

4. The apparent success of a crude system for classifying river banks indicates that it should be possible to develop a more sophisticated scheme for accurately predicting vehicle exiting capability.

Recommendations

1. Vehicle exiting tests should be conducted to verify river exiting performance limits developed by this analysis.

2. A more sophisticated bank classification system should be developed to permit the development of river regime analogs so that extensive river surveys will not be necessary in the future.

LIST OF FIGURES

I. INTRODUCTION

A study by the University of Detroit on river frequency and magnitude in the United States identified the river crossing problem as an exiting problem (Ref. 1). The exiting problem was analyzed as being caused by a high incidence of steep slopes and vertical walls greater than that which existing military vehicles could be expected to negotiate.

With the problem thus defined, the next task was an attempt to relate the survey data with vehicle performance. The vehicle chosen was the M-113, Amphibious Armored, Personnel Carrier. The M-113 was chosen because it is considered to be one of the Army's most mobile amphibious vehicles and because performance and test information was available. The first portion of the analysis consisted of estimating the GO or NO-GO performance of the vehicle for each of the 226 banks surveyed in the eastern portion of the frequency study (Ref. 1).

The results of this analysis showed that the M-113 has limited exiting capability. The major deficiency of the analysis was its qualitative nature. Review indicated that the analysis could be improved by the adoption of a simple scheme for classifying the geometric severity of a river bank as an exiting obstacle.

In developing the geometric classification scheme it was assumed that a vertical wall is the most severe exiting obstacle and that a slope can be represented by some equivalent vertical wall. Therefore, in this scheme, bank severity is a single number which represents the height of an equivalent vertical wall.

The classification scheme was found to work well in rating the qualitative analysis of M-113 performance and in evaluating the limited test data available from the Swamp Fox II exercise (Ref. 2). Therefore, the scheme can be a useful tool when used in the proper perspective.

The desirability of further survey work is indicated to substantiate the finding that excessive bank slopes occur so frequently that there is little probability for existing military vehicles to achieve an unaided exit. A more sophisticated bank classification system should also be developed for the analysis of vehicle concepts.

II. QUALITATIVE ANALYSIS OF M-113 RIVER-EXITING PERFORMANCE

A. Description of Environmental Data.

The river frequency study (Ref. 1) made available a number of approximate river cross-sections. Color slides and a description of the vegetation were also available. The information constituted sufficient basis upon which to make an analysis of M-113 GO or NO-GO exiting performance on each of the river banks measured in the survey.

The analysis considered three aspects of river bank environment:

1. Bank geometry.
2. Vegetation.
3. Soil strength.

Each of these factors was considered as having fixed limits. Immobilizing obstacles which individually would not produce a NO-GO condition were not considered because of an inability to identify their synergism. Fortunately, there were very few cases where such an evaluation would have been required; in most cases, a single factor dominated the analysis.

B. M-113 Performance Criteria.

The rated vertical wall capability of the M-113 is a 24 inch vertical wall constructed from wood timbers or concrete (Ref. 3). The M-113 vertical wall capability is limited by the physical arrangement of its suspension system. The theoretical vertical wall capability of the vehicle is calculated as 2 1/2 to 3 feet (Ref. 4). The vehicle could probably climb a 2 1/2 to 3 foot earth wall, particularly if some relief were present and the vehicle utilized its momentum. Therefore, for this analysis, the vehicle was considered to have a 3 foot vertical earth wall capability.

The rated maximum grade capability of the M-113 is 60 percent (Ref. 3). This is measured on a concrete slope with rubber pads installed on the track. The maximum grade capability on an earth slope, with the vehicle exiting from water, is somewhat less. Aberdeen Proving Ground reports: "The vehicle will successfully exit on banks with 5 percent through 30 percent slopes without regard to bank conditions, i.e., soil, vegetation, etc." (Ref. 5) For the present analysis, therefore, the vehicle was considered to have an absolute maximum of 50 percent earth slope-climbing capability.

Many rivers have dense vegetation along their banks. For an unaided exit, the vehicle must be capable of crushing, uprooting, or shearing off this vegetation. For the present analysis, the M-113 was assumed to be able to negotiate two firmly rooted, 6-inch diameter trees or one 12-inch diameter tree.

Based on the experience of the Land Locomotion Division, qualitative judgment of M-113 soft-soil performance is difficult. Therefore, the maximum vehicle capability was assumed and the vehicle was considered to be able to negotiate the soil unless an extensive marsh or swamp were present.

It appeared, initially, that a large part of the analysis would be based on subjective judgment. Estimating general vehicle cross-country performance requires a rather extensive vehicle background and what could almost be referred to as an occult skill to visualize and relate all of the driver, vehicle, and terrain factors that influence performance. We would be remiss if such an ability were implied in this analysis.

As the analysis progressed, it became evident that much of the measured river environment was extremely severe with respect to M-113 capabilities. Therefore, by relating one environmental factor (slope, vertical wall, marsh, etc.,) to the vehicle performance capability, the evaluation was conducted on a straight forward basis. Thus, it was concluded that for an analysis of this type, sophisticated techniques for predicting exiting capability are not required.

C. Results of Exiting Performance Analysis.

A summary of the survey data is shown in Table I. * Table II shows the performance analysis for the M-113 for the eastern portion of the 43° N. latitude traverse (Grand Haven, Mich. to Boston, Mass.), sites 1 through 69. The NO-GO incidence was 66 percent. The reasons for the NO-GO evaluations were:

1.	Slope greater than 50 percent:	38 percent
2.	Vertical wall greater than 3 feet:	15 percent
3.	Trees:	12 percent
4.	Marsh or swamp:	1 percent

This analysis is illustrated in Figure 1.

Analysis of the eastern portion of the 36° N. latitude traverse (Elizabeth City, N. C. to Knoxville, Tenn.), sites 70 through 115, showed even more

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* All Tables are included in Appendix A.

severe exiting conditions. For this portion of the traverse the NO-GO incidence was 83 percent. The breakdown of NO-GO evaluations shows:

1.	Slope greater than 50 percent:	31 percent
2.	Vertical wall greater than 3 feet:	34 percent
3.	Trees:	2 percent
4.	Marsh or swamp:	16 percent

This analysis is illustrated in Figure 2.

The 16 percent marsh or swamp NO-GO evaluations were made on the basis of marshes or swamps occurring exclusively in the first 90 miles of the traverse (sites 70 through 78). This portion of the traverse was in a low-lying coastal area which included the Dismal Swamp. Heavy vegetation and soft soil conditions make cross-country vehicular travel virtually impossible in this type of terrain.

The tabulation of NO-GO evaluations includes only the primary factor. For example, if a river bank consisted of a steep slope with large trees at the top, the slope was considered the primary factor and was so listed. It can be concluded that the primary cause of M-113 exiting difficulty is steep slopes or vertical walls greater than 3 feet. It should be borne in mind that even if the primary cause of exiting difficulty could be overcome, a secondary cause, which in most cases would be heavy vegetation, might also, by itself, prevent the vehicle from exiting. This type of complication was not considered in the present analysis simply because it was felt that determination of primary causes was of overriding importance and as a first step was sufficient.

The major deficiency of the analysis appeared to be inability to measure the degree of difficulty each bank presented as an exiting obstacle. Thus, while the analysis shows that the vehicle would not be able to exit on 73 percent of the banks surveyed, the analysis does not indicate what additional performance characteristics would be required for an exit.

The analysis shows that in most areas the primary difficulty in exiting can be related to the bank configuration; that is, in 88 percent of the NO-GO cases, the slope is greater than the performance capability of the vehicle. Therefore, a scheme or system which relates river bank geometry to a severity measurement could be used to evaluate most NO-GO cases. Equally important, such a scheme or system could possibly be used to evaluate most of the GO cases.

III. GEOMETRIC SEVERITY CLASSIFICATION SCHEME

A. Objective.

Develop a simple scheme to classify the severity of a river bank as an exiting obstacle. (The scheme was to be suitable for use with the type of input anticipated from simplifed surveys and approximate data from maps and air photos.)

B. Approach.

Examination of a number of bank profiles indicated that, for a first approximation, the bank can be represented by a series of straight lines and slope angles. The severity of the bank would then be the degree to which the bank approaches a vertical wall, which is assumed to be the most severe case. The severity of the slope would, therefore, be a function of the height of the slope reduced by a factor which is a function of the slope angle. The severity of a 90 degree slope, or vertical wall, would be a function of its height only. Overhanging banks and banks with slopes greater than 90 degrees (measured from the horizontal) are considered as vertical walls for classification purposes.

C. Discussion.

The function representing the severity of the height of the slope or wall was chosen simply as the height of the slope or wall in feet because this can be easily measured in the field. The modifying factor for the slope angle was chosen as the sine of the slope angle. The sine has a value of 2.0 for a 90 degree slope or vertical wall and 0.0 for level ground. The severity factor is therefore:

$$s = h \sin \theta \qquad (1)$$

where h is the height of the slope and θ is the slope angle. In cases where the bank is represented by multiple slopes, the severity factor is the sum of the individual factors. This is illustrated in Figure 3.

When the scheme was applied to field survey data (Ref. 1), certain deficiencies became apparent. The usefulness of the scheme in differentiating between M-113 GO and NO-GO conditions was poor because low-angle slopes had too high a numerical value. To reduce the value of the severity factor for low angles it was redefined as:

$$s = \sin^2 \theta \qquad (2)$$

The values for $\sin \theta$ and $\sin^2 \theta$ are shown in Figure 4.

Using equation (2) to evaluate the severity factor, good correlation was obtained between GO and NO-GO evaluations for M-113 performance (see Table III). The scheme was thus found to be useful for assigning numerical values to subjective information. The original evaluation is shown in Table II.

Table IV shows the results of Swamp Fox II (Ref. 2) river exiting tests compared with geometric severity factor ratings. This tabulation shows that the M-113 vehicle could not climb a river bank with a severity factor of 4 1/2 and only once in five trials could the M-113 exit from a river bank with a severity factor of 4. In Table III the highest GO value for S was 2 1/2. The lowest NO-GO value for S was 1 3/4. There is, therefore, some overlapping of GO and NO-GO values. The number of questionable cases was quite small, 6 out of 210. It can, therefore, be concluded, that the existing river exiting tests show that the scheme is reasonable, but may need some refinement.

The scheme has two basic theoretical deficiencies:

1. A very long, gentle slope normally negotiable by a vehicle can have a high severity factor indicating that the bank is not negotiable.

2. A series of steps and/or slopes normally negotiable by a vehicle can have a summation of severity factors indicating that the bank is not negotiable.

These theoretical deficiencies did not appear in the trial evaluation. Examination of the banks surveyed in the study indicates that the above two conditions represent special, rather than general cases. For example, of the 226 banks surveyed on the eastern portion of the survey, only 6. 2 percent had a height-to-depth ratio smaller than 1. 5. It is clear, however, that a more sophisticated classification scheme should account for the bank height-to-depth aspect ratio and the manner in which factors are summed.

The classification scheme used was admittedly crude. However, much of the available information was equally crude and the scheme does allow banks to be classified numerically, which is at least one step above a simple GO or NO-GO judgment.

The need for a more sophisticated bank classification system has been apparent from the outset of the project. Efforts to develop such a system will continue.

The classification system does not take into account soil or vegetation factors, but it can be modified to include these factors if the usefulness of the system in representing geometric properties can be established.

IV. ANALYSIS OF EXITING PERFORMANCE USING THE GEOMETRIC SEVERITY FACTOR.

The M-113 was judged always to be able to negotiate any bank having a geometric severity factor of 2. This was based on the vehicle's rated vertical wall-climbing ability of two feet. * The vehicle was considered to be able to negotiate some banks having a geometric severity factor of between 2 and 4, and not to be able to negotiate any bank with a factor above 4. This upper value was based on the results of the Swamp Fox II exercise (Ref. 2). The groupings used for this analysis were as follows:

Geometric Severity Factor	Vehicle Capability
0 - 2	will negotiate any bank
2 - 4	will negotiate some banks
4	will negotiate no banks

The analysis was conducted only for sites where the magnitude of the slope and/or vertical wall was considered to be the primary factor in whether the vehicle could exit.

A comparison of the two methods used for estimating the M-113 exiting performance is shown in Figures 5 and 6. The general agreement between the two methods is good. The only important difference is the fact that a higher percentage of marginal cases evolved when the geometric severity factor was used.

* Two feet was used for this analysis because the vehicle can always climb a two foot vertical wall, independent of the wall material. In the previous qualitative analysis a three foot earth wall climbing ability was assumed.

Figure 7 shows the distribution of geometric severity factors in the analysis. This is also the distribution of river bank severity for the eastern portion of the survey. The low occurrence, approximately 20 percent, of geometric severity factors of more than 10 is quite significant. It means that approximately 80 percent of the river banks are not insurmountable from a purely geometrical standpoint, if an exiting aid can be developed.

An intensive study of the Black and Huron Rivers in Michigan, conducted by the University of Detroit (Ref. 6), shows that not all rivers are severe obstacles to vehicles. Figures 8 and 9 show the analysis using the geometric severity factor. On the Huron River where 112 banks were surveyed, over a distance along the river of 5.3 miles, the results of the analysis were:

GO	62 percent occurrence
Marginal	17 percent occurrence
NO-GO	21 percent occurrence

On the Black River where 58 banks were surveyed, over a distance of 1.6 miles, the results were:

GO	51 percent occurrence
Marginal	22 percent occurrence
NO-GO	27 percent occurrence

Thus, the analysis clearly shows that for the two rivers examined, the exiting problem is not as severe as that indicated in the magnitude and frequency survey (Ref. 1). This data is shown in Tables V and VI.

The survey did not, however, take into account the confines of the flood plain.* Had this been done, a higher percentage of difficulty would probably have been indicated. This indicates that any future studies should attempt to consider the total riverine environment.

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* Since the survey was only a pilot study conducted before the river crossing problem had been identified as primarily a river exiting problem, it did not include an extensive investigation of banks as obstacles to vehicle exiting.

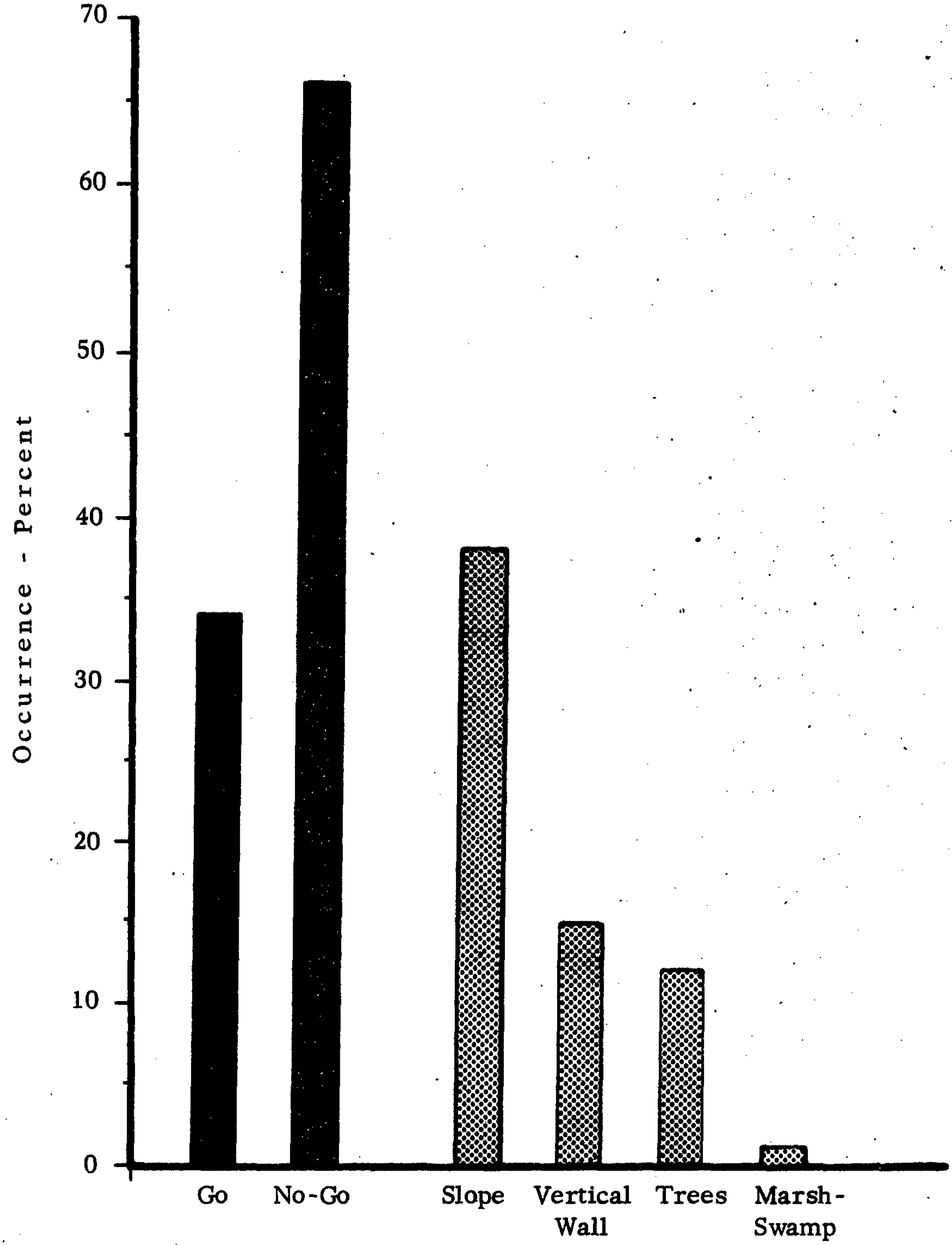
V. CONCLUSIONS

1. The primary reason for vehicle exiting difficulty is the high incidence of slopes and vertical walls which exceed the vehicle design limitations (Figures 1 and 2). River bank geometry is, therefore, the single most important parameter in the river environment.

2. A numerical method, based on a geometric severity factor, can be used to evaluate vehicle exiting performance when bank geometry is the controlling factor (Figures 5 and 6). The apparent success of this crude scheme to classify river banks for their exiting difficulty indicates that it should be possible to develop a more sophisticated system to make accurate predictions.

3. The occurrence of what normally would be considered "insurmountable" river banks is low. This indicates that an adequate exiting aid would probably be successful in materially improving the exiting performance of military amphibious vehicles (Figure 7).

4. Some rivers exist where unaided exits could be accomplished frequently (Figure 8).

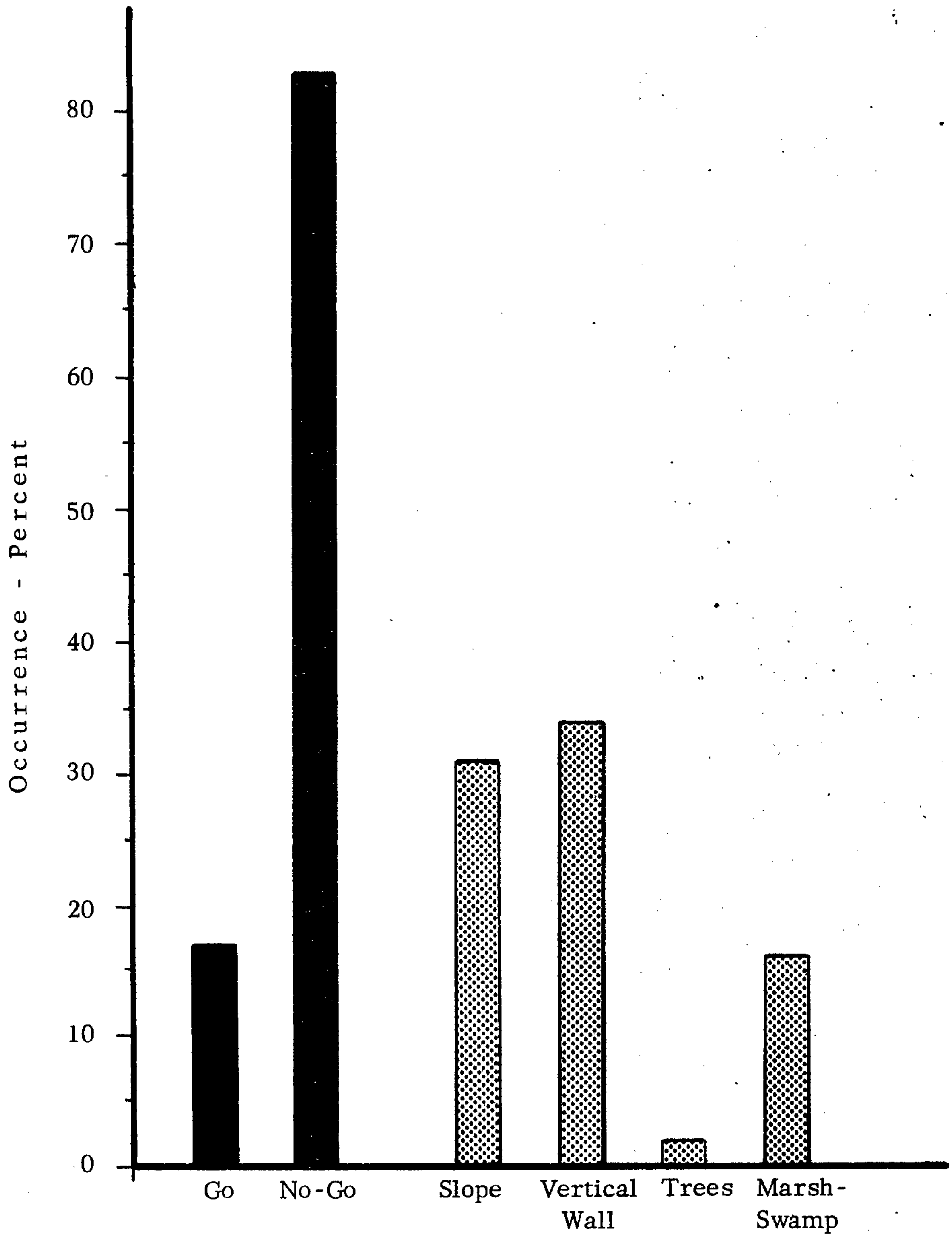


NO-GO ANALYSIS

M-113 EXITING PERFORMANCE

Estimated exiting performance of M-113 for sites 1 through 69 (43° N. latitude traverse, Grand Haven, Mich. to Boston, Mass.).

Figure 1

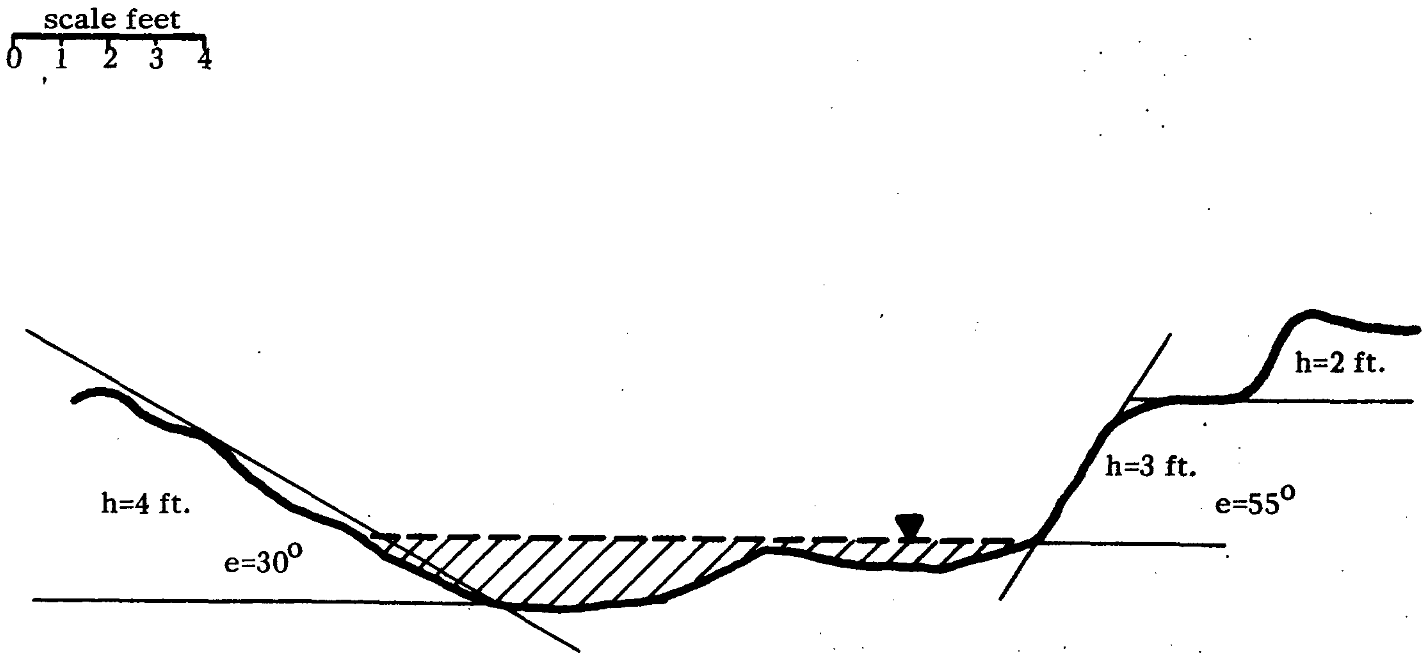


NO-GO ANALYSIS

M-113 EXITING PERFORMANCE

Estimated exiting performance of M-113 for sites 70 through 115 (36^{O} N. latitude traverse, Elizabeth City, N.C. to Knoxville, Tenn.).

Figure 2

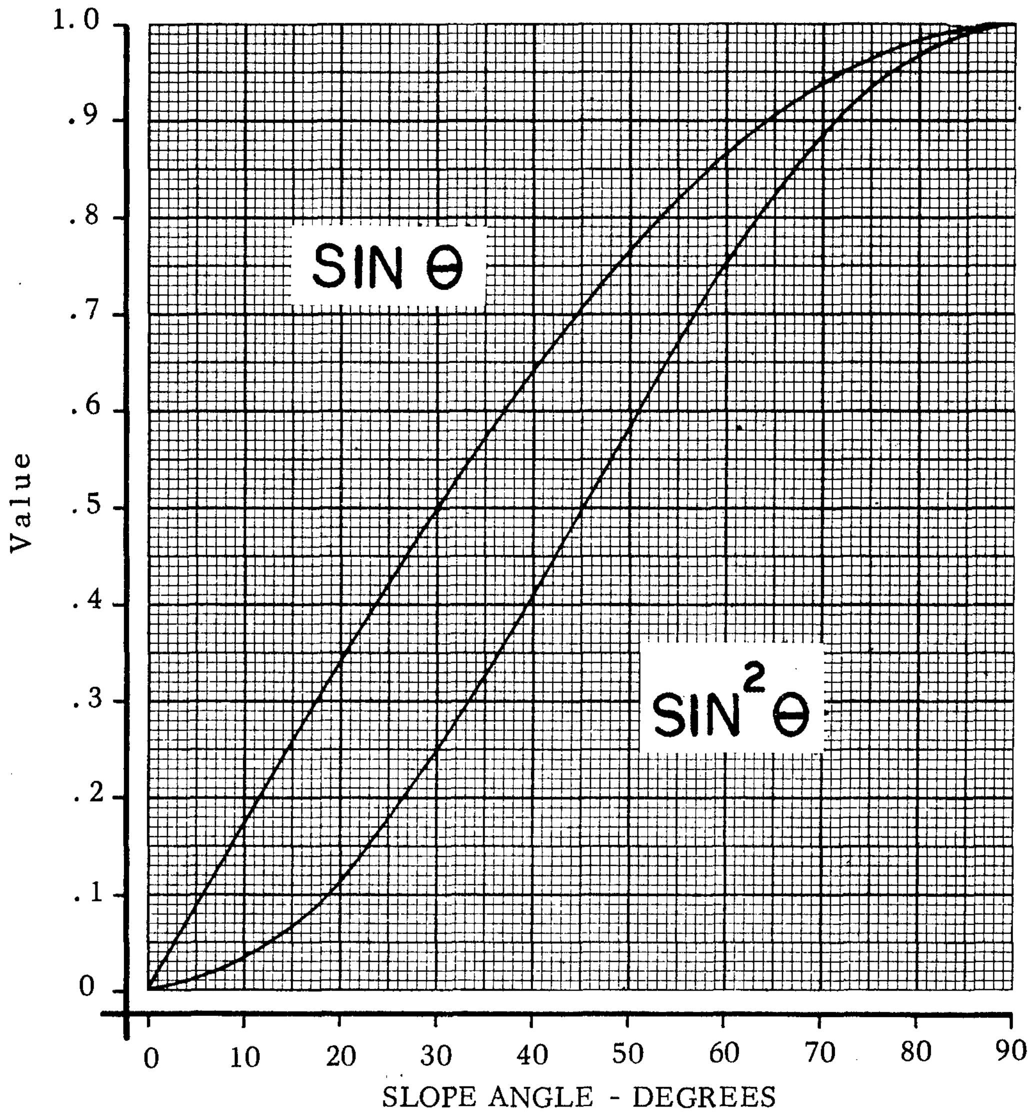


$s = 4 \sin 30^{o} = 2$
$s = 4 \sin^{2} 30^{o} = 1$

$s = (3 \sin 55^{o}) + 2 = 4.3$
$s = 3 \sin^{2} 55^{o} + 2 = 4$

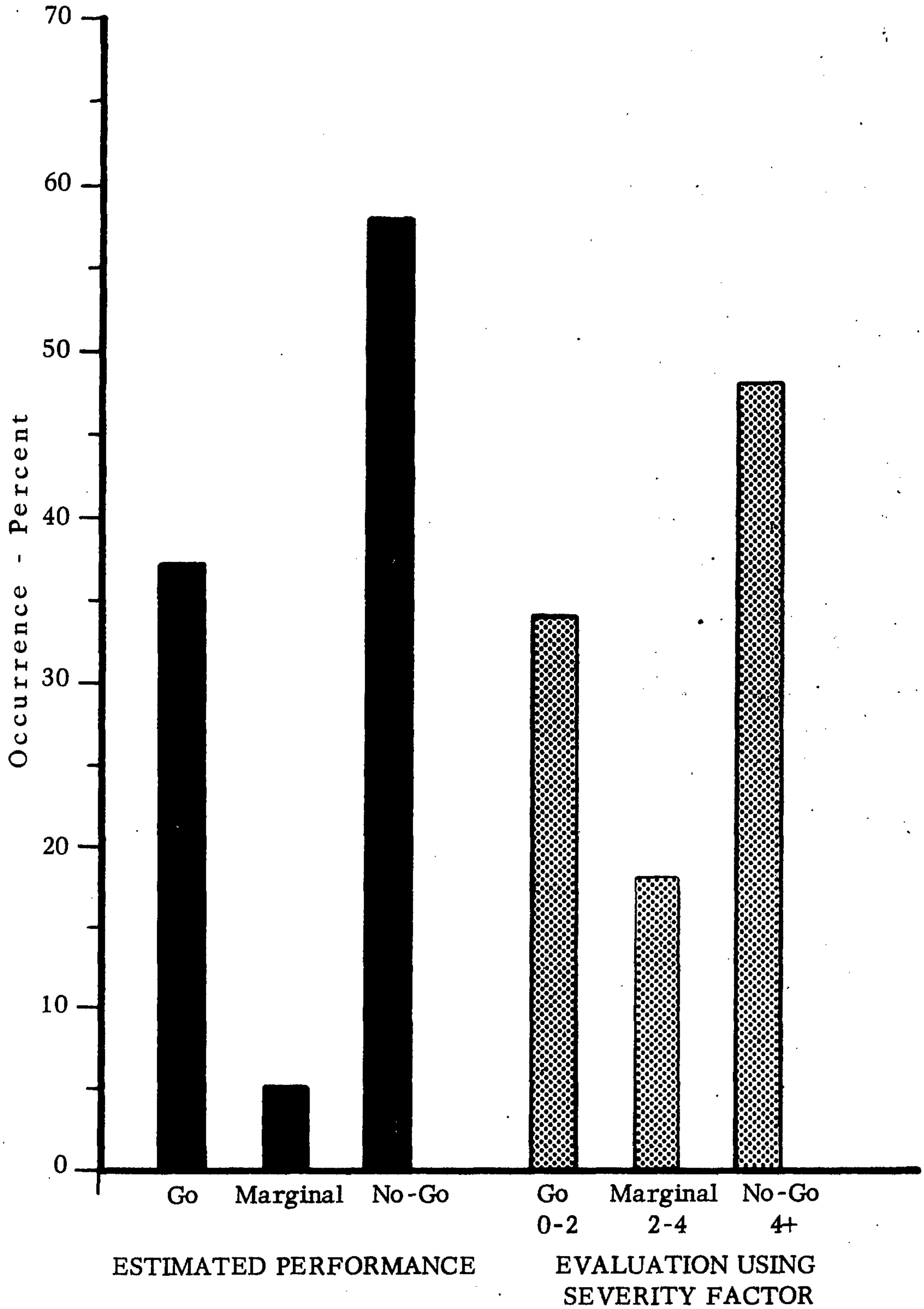
Bank profile showing geometric severity factor determination using $s = h \sin \theta$ and $s = h \sin^{2} \theta$.

Figure 3



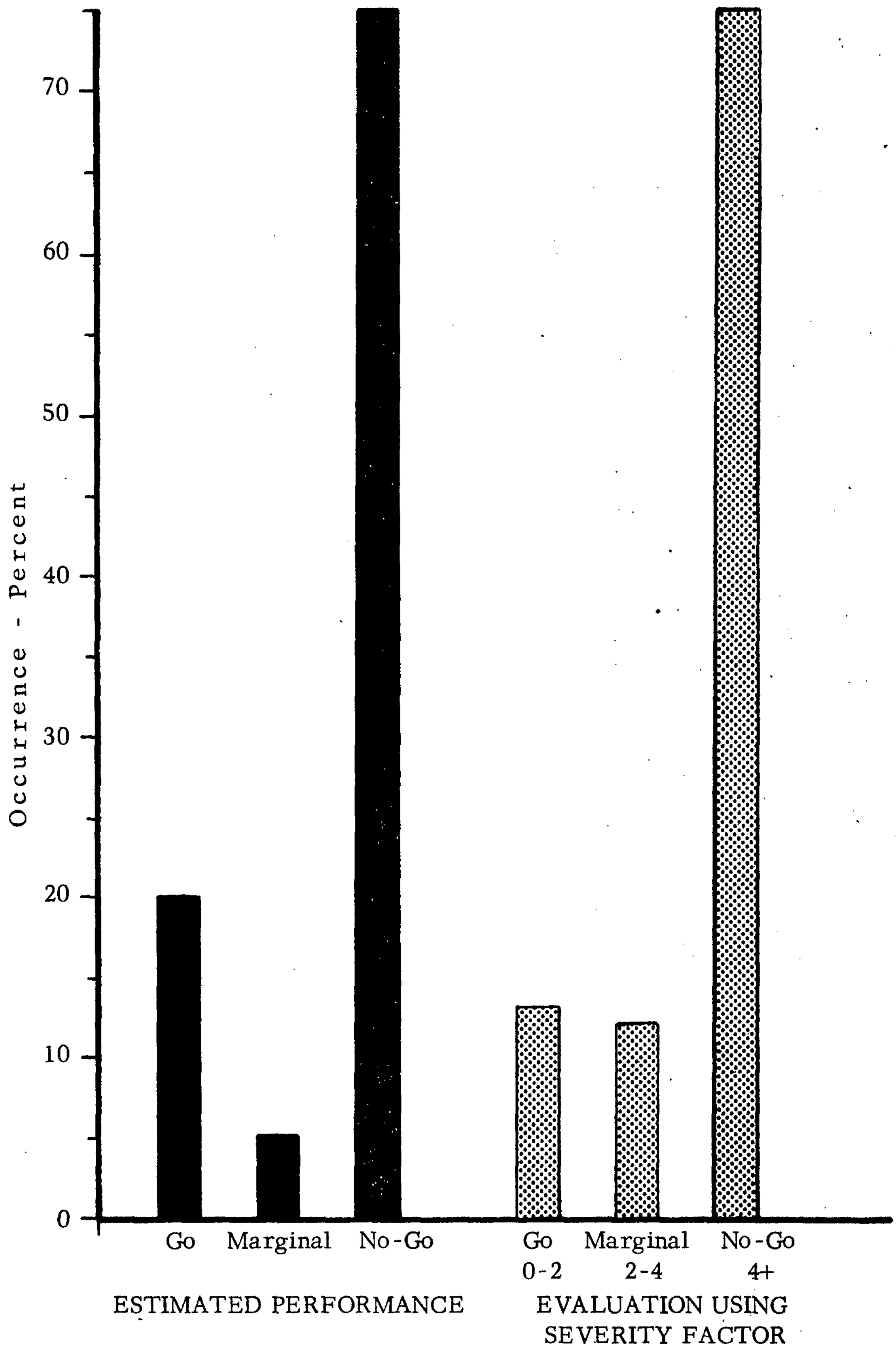
Comparison of sin θ and $\sin^2$ θ.

Figure 4



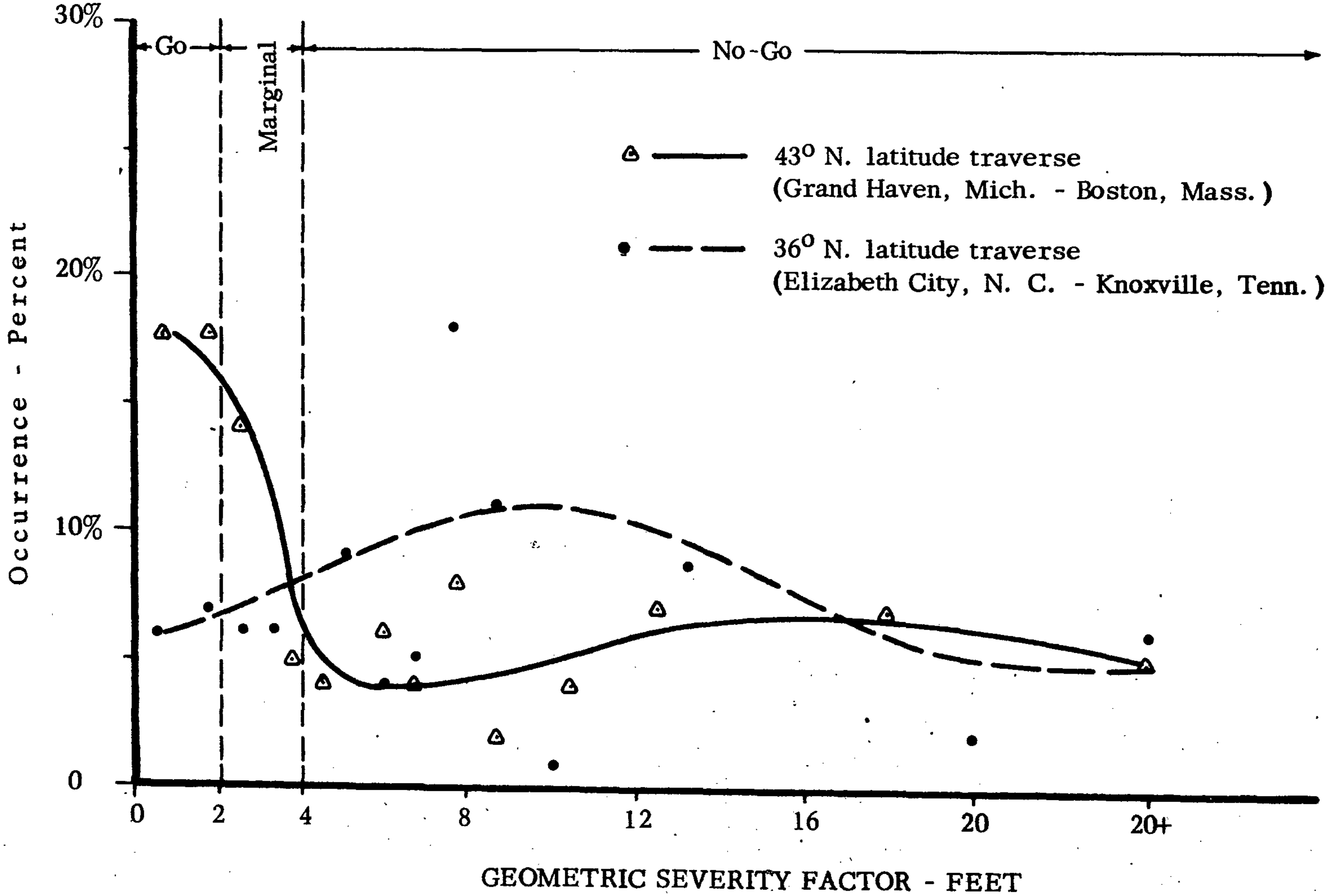
Comparison of methods for estimating M-113 exiting performance for sites 1 through 69 (43^{o} N. latitude traverse, Grand Haven, Mich., to Boston, Mass.).

Figure 5



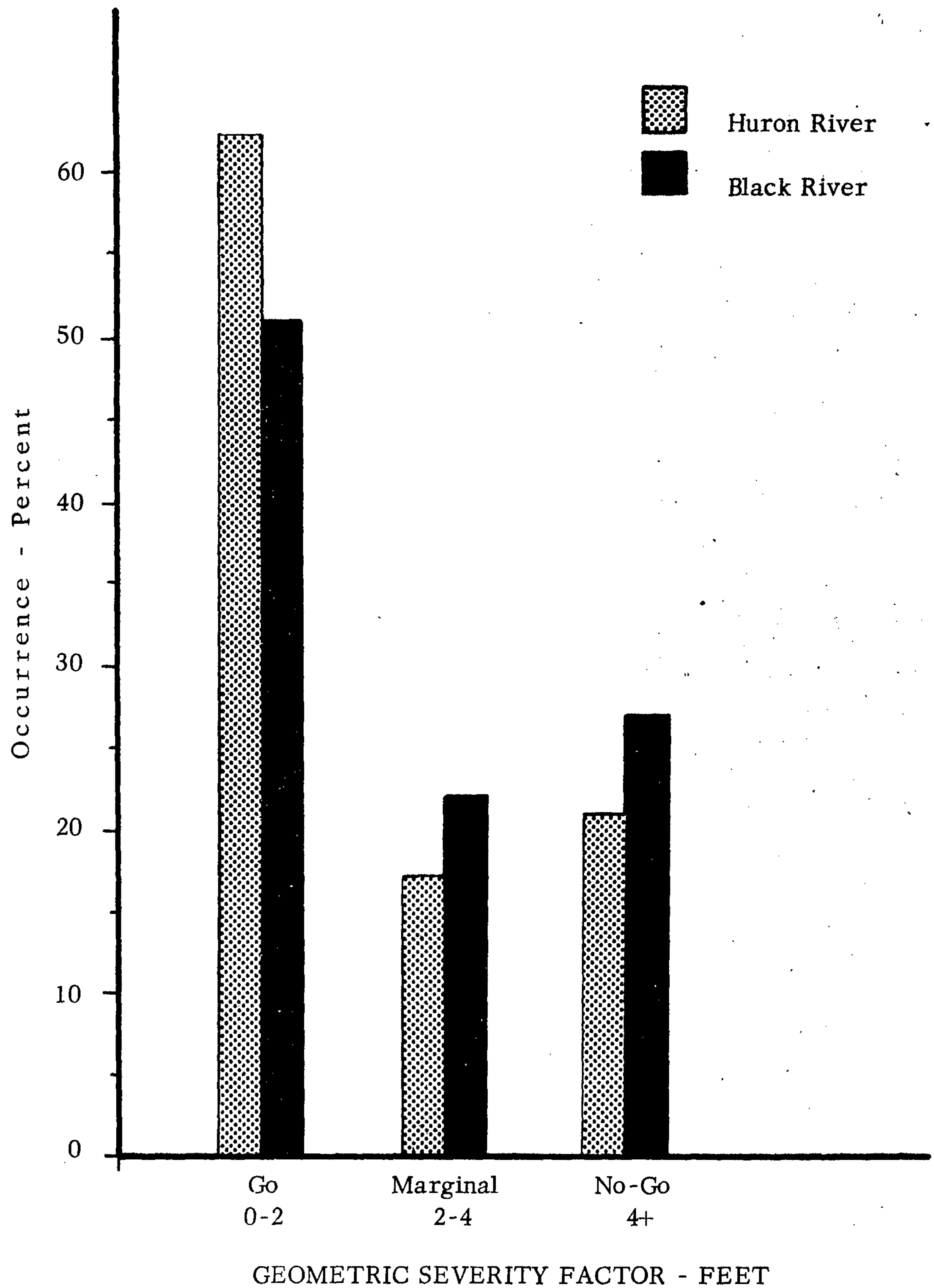
Comparison of methods for estimating M-113 exiting performance for sites 70 through 115 (36^{0} N. latitude traverse, Elizabeth City, N. C., to Knoxville, Tenn.).

Figure 6

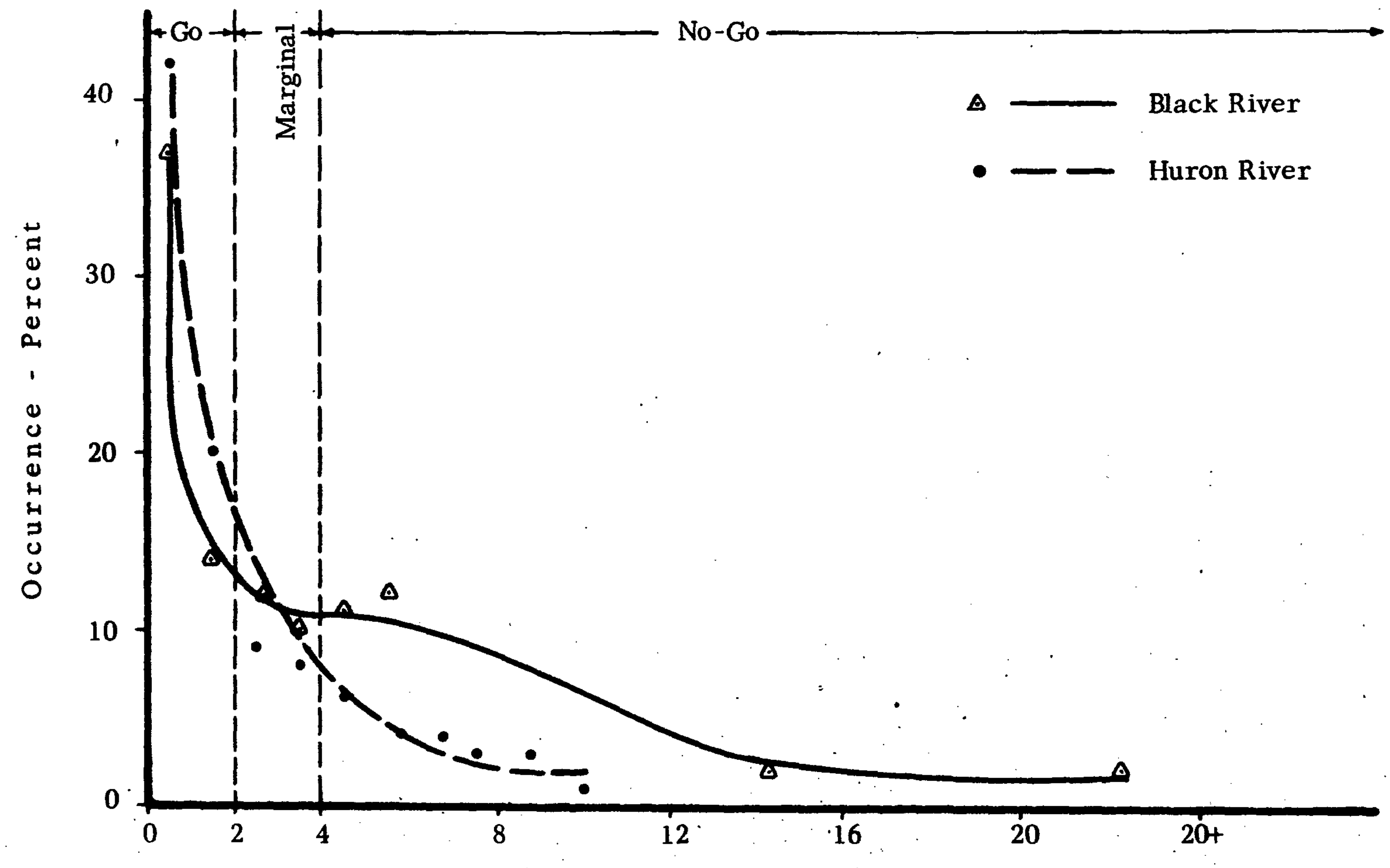


Geometric severity factor occurrence by traverse.

Figure 7



Estimated M-113 exiting performance for the Black and Huron Rivers using the geometric severity factor.
Figure 8



Geometric severity factor occurrence for the Black and Huron rivers.

Figure 9

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APPENDIX A

TABLE I

Data from
"A STUDY OF RIVER MAGNITUDE AND FREQUENCY" (Ref. 1)

43° N. Latitude, Grand Haven, Mich. to Boston, Mass.
Sites 1 - 69

36° N. Latitude, Elizabeth City, N. C. to Knoxville, Tenn.
Sites 70 - 115

Site No.	Miles Between Sites	Bank to Bank Width**	Wetted Water Width	Max. Depth* Feet	Measured Depth Feet	Slope ° Min.	Slope ° Max.	Velocity Ft. / Sec.	
1	49.5***	78	31	21.8	1.8	27	44	1/4	1/2
2	0.5	51	33	37.8	2.8	15	20	1/4	1/2
3	9.0	56	23	7.7	3.7	5	22	0	
4	6.7	31	21	13.2	3.2	15	19	1/4	1/2
5	8.9	109	45	13	1	18	34	1/4	1/2
6	28.0	150	79	9	2	10	37	1/4	1/2
7	10.7	79	35	12.1	2.1	15	40	0	1/4
8	31.6	105	60	15.6	0.6	20	43	0	1/4
9	0.8	155	116	13.2	3.2	15	60	1/4	1/2
10	6.1	51	44	13.5	3.5	90	90	1/4	1/2
11	18.3	750	750	Dam	Dam	90	90	1/4	1/2
12	8.8	371	350	26.7	6.7	5	50	1/4	1/2
13	11.0	500	450	12	2	90	90	2	3
14	11.1	485	450	15	9	16	50	1/4	1/2
15	49.8	800	800	29	25	90	90	6	
16	6.5	68	29	17.3	1.3	40	40	1/4	1/2
17	57.1	85	30	4.5	0.5	5	22	1/4	1/2
18	2.4	289	140	10.9	2.9	3	30	2	3
19	19.0	129	82	6.3	3.3	10	15	1/4	1/2
20	6.5	150	61	5.7	2.7	12	55	1/4	1/2
21	18	128	25	9	2	5	15	2	3
22	12.5	250	74	Dam	6.7	17	45	1/4	1/2
23	12.7	160	31	6.9	3.9	20	40	1/4	1/2
24	9.6	60	34	11.3	2.3	15	35	0	1/4
25	33.9	280	240	19.3	15.3	28	41	1/4	1/2

* Estimated values.
** Width in feet unless miles (m) is specified.
*** Miles from start of traverse.

Site No.	Miles Between Sites	Bank to Bank Width**	Wetted Water Width	Max. Depth* Feet	Measured Depth Feet	Slope° Min.	Max.	Velocity Ft. / Sec.	
26	0.4	550	550	5.8	1.8	90	90	1/2	
27	15.8	94	42	3.7	1.7	10	42	1/4	1/2
28	9.1	128	128	Dam	16.0	90	90	2	3
29	0.2	200	200	Dam	22.0	90	90	2	3
30	19.1	4900*	3900*	Dam	25.0*	90	90	2	3
31	11.7	125	91	6	3*	30	65	1/4	1/2
32	8.4	150	86	2	1*	15	40	0	1/4
33	1.3	225	63	4.5	0.5	29	30	1/4	1/2
34	0.8	260	120	3.8	0.8	30	30	1/4	1/2
35	23.5	72	41	3.3	1.3	7	40	1	
36	12.3	110	82	5.9	0.9	15	25	0	1/4
37	15.0	250	155	18	2*	29	90	1/4	1/2
38	11.7	91	52	7	0	38	50	0	
39	17.8	126	34	4.2	2.2	5	90	1/4	1/2
40	21.8	70	70	5.9	2.9	0	90	0	
41	10.1	300	275	17.8	14.8	7	40	1/4	1/2
42	18.5	41	20	Dam	1*	32	85	2	
43	15.1	41	36	9.1	4.1	60	60	0	1/4
44	16.9	50	33	7.1	1.6	7	90	4	
45	4.3	42	29	6.6	1.6	24	35	2	
46	17.2	70	27	3.8	1.8	29	65	1/2	1
47	18.6	47	28	2.9	0.9	10	60	1/2	1
48	56.5	450	240	12	1	10	11	1/4	1/2
49	14.9	118	67	9.5	4.5	35	45	0	1/4
50	20.6	260	240	10	1	54	54	0	1/4
51	0.3	500	460	29	20	31	90	1/2	1
52	22.6	103	59	5.4	1.4	5	31	2	
53	13.7	63	28	3	1	30	45	4	5
54	2.9	270	238	4.5	1.5	24	24	1/2	1
55	0.7	380	170	4	1*	20	20	1/2	1
56	1.7	50	50	4	2	90	90	2	
57	13.3	85	36	5	2	47	60	4	5
58	5.7	410	295	5.3	2.3	9	16	1	1-1/2
59	2.3	65	20	3.8	0.8	24	24	1	1-1/2
60	7.3	473	300	5.5	2.5	17	26	1/4	1/2
61	1.1	525	255	8.2	2.2	17	30	1-1/2	2
62	10.8	130	81	9	2	10	60	1/4	1/2
63	4.5	210	35	3.5	0.5	39	52	1	

Site No.	Miles Between Sites	Bank to Bank Width**	Wetted Water Width	Max. Depth* Feet	Measured Depth Feet	Slope° Min.	Slope° Max.	Velocity Ft. / Sec.	
64	3.6	730	360	Dam	7*	33	75	1	
65	10.4	305	180	10	1	5	35	2	
66	38.6	224	130	4.5	1.5	13	51	1	
67	6.3	185	155	4	3	90	90	0	1/4
68	15.2	136	109	10	4	5	50	1/4	1/2
69	19.3	240	200	Dam	4*	90	90	1/4	1/2
70	20.0***	500	500	9.2	4.2	0	90	1/4	1/2
71	10.1	23	23	5.6	4.1	0	0	1/4	1/2
72	9.3	1/2 m *	1/2 m*	11	10	0	0	1/4	1/2
73	14.9	104	44	6.4	5.4	0	0	0	
74	0.8	425	425	9.4	8.4	0	0	0	
75	3.5	1.6m +*	1.6m+*	11	10*	0	0	0	
76	5.2	71	71	14.1	13.1	0	0	0	1/4
77	12.3	131	90	12.8	11.8	0	8	0	
78	13.2	280	280	4	2*	0	90	3	
79	34.2	210	105	9	2	20	90	1	
80	21.5	64	54	9	3.5	45	63	1/2	
81	2.1	70	54	5.5	3.5	90	90	0	1/4
82	7.9	35	29.5	3.5	1.5	55	70	0	1/4
83	10.8	120	107	5.5	1.5	90	90	1/2	
84	4.5	25	25	5.2	2.2	0	0	1/4	
85	27.9	108	98	4.5	0.5	45	90	1/4	
86	31.0	55	53	6.2	2.2	90	90	1/4	1/2
87	7.9	51	41	7.5	1.5	54	90	1/4	
88	11.4	65	65	Dam	3*	90	90	1-1/2	
89	19.7	68	38	11.2	1.2	35	40	1/4	1/2
90	15.7	140	140	9.3	3.3	90	90	0	
91	17.7	50	41	12	7	70	70	1/2	1
92	2.7	53	45	11	1	70	70	0	1/4
93	16.1	64	48	11	1	36	90	1/2	1
94	11.0	255	240	12	2*	50	90	2	
95	7.9	56	41	13.2	2.2	36	70	1/4	1/2
96	11.7	125	100	6	2	20	90	2	
97	5.0	80	80	13.2	2.2*	90	90	2	
98	24.5	500	500	Dam	6*	90	90	1/4	1/2
99	50.7	34	31	14	4	70	90	2	
100	17.2	48	48	5.3	1.3	90	90	2	
101	0.7	51	38	5.9	1.9	35	45	3	

*** Miles from start of new traverse, 36° N. latitude.

Site No.	Miles Between Sites	Bank to Bank Width**	Wetted Water Width	Max. Depth* Feet	Measured Depth Feet	Slope° Min.	Slope° Max.	Velocity Ft. / Sec.
102	3.4	100	43	2.3	0.8	25	70	2
103	19.1	115	80	3.3	1.3	38	38	1/2
104	These sites were omitted when a new route was selected because of heavy							
105	fog. The distance between sites 103 and 106 is 17.4 miles as shown.							
106	17.4	111	36	4.3	2.3	40	54	3
107	2.1	65	44	6	1	70	90	3
108	8.0	145	52	7	3	15	80	4
109	15.4	170	70	5.7	4.2	18	54	2
110	6.2	540	310	6	5*	5	11	5
111	0.2	57	37	6.5	2.5	13	13	2
112	11.1	520	450	5.5	4*	16	60	1-1/2
113	12.4	400	350	13	4*	10	90	5
114	4.5	160	150+	13.7	12.7	30	90	2
115	44.3	295	280	10.1	2.6	90	90	1/4 1/2

TABLE II

QUALITATIVE ANALYSIS OF

M-113 RIVER EXITING PERFORMANCE

43^{o} N. Latitude (Grand Haven, Mich. to Boston, Mass.),
Sites 1 - 69

36^{o} N. Latitude (Elizabeth City, N. C. to Knoxville, Tenn.)
Sites 70 - 115

Site	Go	No-Go	Remarks*
1E		X	slope > 26^{o} (44^{o})
1W		X	slope > 26^{o} (41^{o})
2E	X		1 foot wall + 15^{o} slope
2W	X		1 foot wall + 20^{o} slope
3E	X		2 foot wall + 5^{o} slope
3W	X		1-1/2 foot wall + 22^{o} slope
4E	X		2-3 foot 70^{o} slope then 15^{o} slope v. c. m.
4W	X		2-3 foot 70^{o} slope then 19^{o} slope v. c. m.
5E		X	slope > 26^{o} (2 ft. vert. wall + 12 1/2 ft. 34^{o} slope)
5W	X		18^{o} slope
6E		X	20 ft. 37^{o} slope
6W	X		3 ft. 56^{o} slope n. w. m.
7E	X		10 ft. 27^{o} slope m. c.
7W	X		4 ft. 40^{o} slope
8E	X		6 ft. 20^{o} slope
8W		X	slope > 26^{o} (8 ft. 43^{o} + 15 ft. 31^{o})
9E	X		4 ft. 35^{o} slope n. w. m.
9W		X	slope > 26^{o} (5 ft. 60^{o} slope) m. c.
10E		X	trees + vertical wall (4 ft.)
10W		X	trees + vertical wall (3 ft.)
11E		X	vertical wall (3 ft. above water; rock)
11W		X	vertical wall (15 ft.)

* n. w. m. = negotiable with momentum
m. c. = marginal case
v. c. m. = vehicle could modify

Site	Go	No-Go	Remarks
12E	X		2 ft. 45^{o} slope n. w. m.
12W		X	slope $>26^{o}$ (16 ft. 50^{o} slope)
13E		X	vertical wall (20 ft. retaining wall)
13W		X	vertical wall (20 ft. retaining wall)
14E		X	slope $>26^{o}$ (7 ft. 50^{o} slope) and trees
14W		X	slope $>26^{o}$ (8 ft. 31^{o} slope) and trees
15E		X	10 ft. vertical wall, above water, rock fill
15W		X	10 ft. vertical wall, above water, rock fill
16E		X	slope $>26^{o}$ (20 ft. 44^{o} slope) some trees
16W		X	slope $>26^{o}$ (14 ft. 40^{o} slope) some trees
17E	X		5^{o} slope
17W	X		9^{o} slope
18E	X		5 ft. 3^{o} slope + 2 ft. vertical wall + trees
18W		X	vertical wall (20 ft. 30^{o} + 20 ft. vertical wall + trees)
19E	X		10^{o} to 15^{o} slope
19W	X		2 ft. vertical wall + 15^{o} slope
20E		X	vertical wall (11ft. 80^{o})
20W		X	slope $>26^{o}$ (12 ft. 55^{o})
21E	X		15^{o} slope
21W		X	4 ft. vertical wall + trees
22E		X	slope $>26^{o}$ (15 ft. 44^{o} + trees)
22W		X	marsh and slope $>26^{o}$ (marsh + 40 ft. 45^{o})
23E		X	slope $>26^{o}$ (5 ft. 32^{o} + 6 ft. vertical wall)
23W		X	vertical wall (3 ft. high + 22 ft. 40^{o} + trees)
24E		X	slope $>26^{o}$ (6 ft. 56^{o})
24W	X		3 ft. 35^{o} slope n. w. m., m. c.
25E		X	slope $>26^{o}$ (4-1/2 ft. 41^{o}) m. c.
25W		X	slope $>26^{o}$ (13 ft. 28^{o})
26E		X	vertical wall (6 ft. steel retaining wall)
26W		X	marsh
27E	X		8 ft. 24^{o}
27W		X	slope $>26^{o}$ (12 ft. 42^{o})
28E		X	vertical wall (16 ft. Old Welland Canal)
28W		X	vertical wall (16 ft. Old Welland Canal)
29E		X	vertical wall (30 ft. New Welland Canal)
29W		X	vertical wall (30 ft. New Welland Canal)
30E		X	8 ft. concrete wall
30W		X	8 ft. concrete wall
31E		X	slope $>26^{o}$ (15 ft. 55^{o})
31W		X	slope $>26^{o}$ (3 ft. 65^{o} + 15 ft. 30^{o})

Site	Go	No-Go	Remarks
32E		X	slope > 26° (19 ft. 40°)
32W	X		9 ft. 25°
33E		X	slope > 26° (4 ft. vertical wall + 15 ft. 30° slope)
33W		X	slope > 26° (17 ft. 29°)
34E		X	slope > 26° (30 ft. 30°)
34W		X	slope > 26° (30 ft. 30°)
35E		X	slope > 26° (10 ft. 32°)
35W		X	slope > 26° (3 ft. vert. wall + 7 ft. 40° slope)
36E	X		10 ft. 22°
36W	X		4 ft. 25°
37E		X	slope > 26° (13 ft. 55°)
37W		X	slope > 26° (18 ft. 29°)
38E		X	slope > 26° (5 ft. 38°)
38W		X	slope > 26° (18 ft. 55°)
39E	X		1 ft. vertical wall + 5° slope
39W	X		2 ft. vertical wall + 7° slope
40E		X	marsh m.c.
40W		X	vertical wall (4-1/2 ft. retaining wall)
41E	X		2 ft. 40°
41W	X		5 ft. 28° n.w.m.
42E	X		4-1/2 ft. 65° n.w.m., m.c.
42W		X	slope > 26° (7 ft. 32°)
43E		X	slope > 26° (4-1/2 ft. 61°)
43W		X	slope > 26° (4-1/2 ft. 61°)
44E		X	vertical wall 4 ft., m.c.
44W	X		2 ft. 40°
45E	X		6-1/2 ft. 35° n.w.m., m.c.
45W	X		2 ft. 24°
46E		X	slope > 26° (10 ft. 29°)
46W		X	slope > 26° (20 ft. 65°)
47E	X		2-1/2 ft. 29°
47W	X		4 ft. 10°
48E	X		35 ft. 10°
48W		X	slope > 26° (6 ft. 10° + 8 ft. 60° + 12 ft. 10°)
49E		X	slope > 26° (45° slope + trees)
49W		X	slope > 26° (7 ft. 37° + trees)
50E		X	slope > 26° (25 ft. 54° slope)
50W		X	slope > 26° (25 ft. 54° slope)
51E		X	20 ft. vertical wall
51W		X	slope > 26° (23 ft. 31° slope)

Site	Go	No-Go	Remarks
52E	X		maximum slope 20^{o}
52W		X	slope > 26^{o} (7 ft. 31^{o} slope)
53E		X	slope > 26^{o} (12 ft. 45^{o} slope)
53W		X	slope > 26^{o} (8 ft. 30^{o} slope)
54E	X		14 ft. 24^{o} slope
54W	X		14 ft. 24^{o} slope
55E	X		27 ft. 20^{o} slope
55W	X		27 ft. 20^{o} slope
56E		X	16 ft. vertical wall
56W		X	16 ft. vertical wall
57E		X	12 ft. vertical wall
57W		X	slope > 26^{o} (12 ft. 60^{o} slope)
58E	X		20 ft. 16^{o} slope
58W	X		9 ft. 9^{o} slope
59E	X		7 ft. 24^{o} slope
59W	X		7 ft. 24^{o} slope
60E	X		28 ft. 17^{o} slope
60W		X	slope > 26^{o} (41 ft. 26^{o} slope)
61E		X	slope > 26^{o} (30 ft. 30^{o} slope)
61W	X		30 ft. 17^{o} slope
62E		X	2 ft. vertical wall + 4 ft. 60^{o} slope
62W		X	4 ft. vertical wall
63E		X	slope > 26^{o} (110 ft. 52^{o} slope + trees)
63W		X	slope > 26^{o} (38 ft. 39^{o} slope + trees)
64E		X	slope > 26^{o} (150 ft. 33^{o} slope + trees)
64W		X	slope > 26^{o} (50 ft. 75^{o} slope + trees)
65E	X		2 ft. 5^{o} slope
65W		X	slope > 26^{o} (22 ft. 35^{o} slope + trees)
66E		X	slope > 26^{o} (70 ft. 51^{o} slope + trees)
66W		X	3 ft. vertical wall + trees
67E	X		4 ft. 15^{o} slope
67W	X		1-1/2 ft. vertical wall + 3 ft. 15^{o} slope
68E	X		1-1/2 ft. vertical wall + 1-1/2 ft. 15^{o} slope
68W		X	slope > 26^{o} (15 ft. 50^{o} slope)
69E	X		2 ft. vertical wall + 1-1/2 ft. 12^{o} slope
69W	X		2 ft. vertical wall + 3 ft. 9^{o} slope
70E		X	Swamp
70W		X	5 ft. vertical wall
71E		X	Swamp
71W		X	Swamp

Site	Go	No-Go	Remarks
72E		X	Swamp
72W		X	Swamp
73E	X		4-1/2 ft. 11^{o} slope
73W		X	Swamp
74E		X	Swamp
74W		X	Swamp
75E		X	Swamp
75W		X	Swamp
76E		X	Swamp
76W		X	Swamp
77E		X	Swamp
77W	X		6 ft. 8^{o} slope
78E		X	Swamp
78W		X	5 ft. vertical wall
79E	X		17 ft. 20^{o} slope
79W		X	8 ft. vertical wall
80E		X	slope > 26^{o} (8 ft. 63^{o} slope + trees)
80W		X	slope > 26^{o} (6 ft. 45^{o} slope + trees)
81E		X	5-1/2 ft. vertical wall + trees
81W		X	8-1/2 ft. vertical wall + trees
82E		X	slope > 26^{o} (4 ft. 70^{o} slope + trees)
82W		X	slope > 26^{o} (4 ft. 45^{o} slope + trees)
83E		X	14 ft. vertical wall + trees
83W		X	14 ft. vertical wall + trees
84E	X		slope < 26^{o}
84W		X	slope > 26^{o}
85E		X	12 ft. vertical wall
85W		X	slope > 26^{o} (10 ft. 45^{o} slope)
86E	X		3-1/2 ft. vertical wall n. w. m., m. c.
86W	X		2-1/2 ft. vertical wall
87E		X	slope > 26^{o} (11 ft. 54^{o} slope + trees)
87W		X	9 ft. vertical wall + trees
88E		X	6 ft. vertical wall
88W		X	6 ft. vertical wall
89E		X	slope > 26^{o} (10 ft. 35^{o} slope)
89W		X	slope > 26^{o} (10 ft. 40^{o} slope)
90E		X	5 ft. vertical wall + trees
90W		X	6.5 ft. vertical wall + trees
91E		X	slope > 26^{o} (6 ft. 70^{o} slope)
91W		X	slope > 26^{o} (6 ft. 70^{o} slope)

Site	Go	No-Go	Remarks
92E		X	slope > 26^o (10 ft. 70^o slope)
92W		X	slope > 26^o (10 ft. 70^o slope)
93E		X	9 ft. vertical wall
93W		X	slope > 26^o (17-1/2 ft. 36^o slope)
94E		X	slope > 26^o (14 ft. 50^o slope + trees)
94W		X	8 ft. vertical wall + trees
95E		X	slope > 26^o (7 ft. 36^o slope)
95W		X	slope > 26^o (6 ft. 70^o slope + 5 ft. 50^o slope)
96E	X		2 ft. vertical wall + 7 ft. 20^o slope
96W		X	8 ft. vertical wall
97E		X	6 ft. vertical wall
97W		X	6 ft. vertical wall
98E		X	8 ft. vertical wall
98W		X	8 ft. vertical wall
99E		X	slope > 26^o (8-1/2 ft. 70^o slope)
99W		X	8-1/2 ft. vertical wall
100E		X	9 ft. vertical wall
100W		X	8 ft. vertical wall
101E	X		5 ft. 35^o slope n. w. m., m. c.
101W	X		5 ft. 45^o slope n. w. m., m. c.
102E		X	slope > 26^o (300 ft. 70^o + trees)
102W	X		4 ft. 25^o slope
103E		X	slope > 26^o (33 ft. 38^o slope)
103W		X	slope > 26^o (30 ft. 38^o slope)
104			
105			
106E		X	slope > 26^o (18 ft. 40^o slope)
106W		X	slope > 26^o (100 ft. 54^o slope)
107E		X	slope > 26^o (9 ft. 70^o slope)
107W		X	slope > 26^o (14 ft. 64^o slope)
108E		X	slope > 26^o (50 ft. 80^o slope)
108W		X	slope > 26^o (20 ft. 40^o slope)
109E		X	slope > 26^o (10 ft. 54^o slope)
109W		X	slope > 26^o (70 ft. 50^o slope)
110E	X		27 ft. 11^o slope
110W		X	8 ft. vertical wall
111E		X	buildings (vertical wall)
111W		X	buildings (vertical wall)
112E		X	slope > 26^o (25 ft. 60^o slope)
112W		X	18 ft. vertical wall

Site	Go	Go-No	Remarks
113E	X		9 ft. 10° slope
113W		X	10 ft. vertical wall + trees
114E	X		5 ft. 30° slope n. w. m.
114W		X	36 ft. vertical wall
115E	X		2 ft. vertical wall + 4 ft. 18° slope
115W		X	7-1/2 ft. vertical wall

TABLE III

ANALYSIS OF
M-113 RIVER EXITING PERFORMANCE
USING THE GEOMETRIC SEVERITY FACTOR

	Data from original field notes						Severity factor**	Qualitative
Site*	h	θ	h	θ	h	θ	$s=h(\sin\theta)^2$	Evaluation***
1E	14	41°	5	31°			7-1/2	No-Go
1W	8	44°	11.5	27°			6-1/4	No-Go
2E	2	15°	1	90°			1-1/4	Go
2W	4	20°					1/2	Go
3E	2	90°	2	5°			2	Go
3W	1-1/2	90°	7-1/2	22°			2-1/4	Go
4E	2-1/2	70°	1	15°			2-1/4	Go
4W	3/4	90°	2	19°			1	Go
5E	2	90°	12-1/2	31°			5-1/4	No-Go
5W	14	17°					1	Go
6E	20	37°					7	No-Go
6W	1-1/2	10°	3	55°	3	25°	2-1/2	Go
7E	10	27°	1-1/2	90°			1-3/4	Go
7W	4	40°	11	15°			2-1/2	Go
8E	6	20°					3/4	Go
8W	2	25°	9	43°	6	21°	5-1/4	No-Go
9E	3-1/2	35°	2	15°			1-1/4	Go
9W	5	60°					3-3/4	No-Go
10E	3-1/2	90°					3-1/2	No-Go
10W	3	90°					3	No-Go
11E	15	90°					15	No-Go
11W	3	90°					3	No-Go
12E	1	5°	2	45°			1	Go
12W	16	50°					9-1/4	No-Go
13E	20	90°					20	No-Go
13W	20	90°					20	No-Go

* E and W refer to East and West banks.

** Values to nearest 1/4.

*** M-113 exiting performance evaluation based on judgment and vehicle performance of 50 percent grade and a 3 ft. vertical wall capability.

Site	Data from original field notes h	θ	h	θ	h	θ	Severity factor $s=h(\sin\theta)^2$	Qualitative Evaluation
14E	7	50°					4	No-Go
14W	5-1/2	16°	8	31°			2-1/2	No-Go
15E	10	90°					10	No-Go
15W	10	90°					10	No-Go
16E	20	44°					9-3/4	No-Go
16W	14	40°					5-3/4	No-Go
17E	1	15°	1-1/2	5°			1/4	Go
17W	6	22°	1-1/2	9°			3/4	Go
18E	1	3°	2	90°	13-1/2	12°	2-1/2	Go
18W	2	10°	5	30°	20	90°	21	No-Go
19E	3-1/2	10°	3	15°			1/2	Go
19W	2	90°	3	15°			2-1/4	Go
20E	5	15°	11	78°			10-3/4	No-Go
20W	12	55°					8	No-Go
21E	2	15°					1/4	Go
21W	4	90°					4	No-Go
22E	15	44°	9	17°			8-1/2	No-Go
22W	40	45°					20	No-Go
23E	5	32°	6	90°			7-1/4	No-Go
23W	3	90°	22	40°			12	No-Go
24E	6	56°					4	No-Go
24W	3	35°					1	Go
25E	4-1/2	41°					1-3/4	No-Go
25W	13	28°					2-1/2	No-Go
26E	6	90°					6	No-Go
26W	Marsh							No-Go
27E	8	24°					1-1/2	Go
27W	12	42°					5	No-Go
28E	16	90°					16	No-Go
28W	16	90°					16	No-Go
29E	30	90°					30	No-Go
29W	30	90°					30	No-Go
30E	8	90°					8	No-Go
30W	8	90°					8	No-Go
31E	15	55°					10	No-Go
31W	3	65°	15	30°			6-1/4	No-Go
32E	19	40°					7-3/4	No-Go
32W	9	25°					1-1/2	Go

Site	Data from original field notes h	θ	h	θ	h	θ	Severity factor $s=h(\sin\theta)^2$	Qualitative Evaluation
33E	4	90°	15	30°			7-3/4	No-Go
33W	17	29°					4-1/4	No-Go
34E	30	30°					7-1/2	No-Go
34W	30	30°					7-1/2	No-Go
35E	10	32°					2-3/4	No-Go
35W	3	90°	7	40°			6	No-Go
36E	10	22°					1-1/4	Go
36W	4	25°					3/4	Go
37E	13	55°					8-3/4	No-Go
37W	18	29°					4-1/2	No-Go
38E	5	38°					2	No-Go
38W	18	55°					12	No-Go
39E	1	90°	2	5°			1	Go
39W	2	90°	7-1/2	6°			2	Go
40E	Marsh							No-Go
40W	4-1/2	90°					4-1/2	No-Go
41E	2	40°					3/4	Go
41W	5	28°					1-1/4	Go
42E	4-1/2	65°					1-3/4	Go
42W	7	32°					1-3/4	No-Go
43E	4-1/2	61°					3-1/2	No-Go
43W	4-1/2	61°					3-1/2	No-Go
44E	4	90°					4	No-Go
44W	2	40°					1	Go
45E	6-1/2	35°					2-1/4	Go
45W	2	24°					1/4	Go
46E	10	29°					2-1/2	No-Go
46W	20	65°					17-1/2	No-Go
47E	2-1/2	29°					3/4	Go
47W	4	10°					0	Go
48E	3-1/2	10°	2	5°	29	10°	1/2	Go
48W	6	10°	8	60°	12	10°	6-3/4	No-Go
49E	3-1/2	35°	8-1/2	45°	26	35°	14	No-Go
49W	7	37°					2-1/2	No-Go
50E	25	54°					10-3/4	No-Go
50W	25	54°					10-3/4	No-Go
51E	20	90°					20	No-Go
51W	23	31°					5-3/4	No-Go
52E	2	20°	3	10°	2	20°	1/2	Go
52W	7	31°					1-3/4	No-Go

	Data from original field notes						Severity factor	Qualitative
Site	h	θ	h	θ	h	θ	$s=h(\sin\theta)^2$	Evaluation
53E	12	45^o					6	No-Go
53W	8	30^o					2	No-Go
54E	14	24^o					2	Go
54W	14	24^o					2	Go
55E	27	20^o					2-3/4	Go
55W	27	20^o					2-3/4	Go
56E	16	90^o					16	No-Go
56W	16	90^o					16	No-Go
57E	12	90^o	5	45^o			14-1/2	No-Go
57W	12	60^o					9	No-Go
58E	20	16^o					2-1/2	Go
58W	9	9^o					1/4	Go
59E	7	24^o					1	Go
59W	7	24^o					1	Go
60E	28	17^o					2	Go
60W	41	26^o					7-1/2	No-Go
61E	3	17^o					7-1/2	No-Go
61W	30	17^o					2	Go
62E	2	90^o	1-1/2	15^o	5	60^o	5-3/4	No-Go
62W	7	10^o	4	90^o			4-1/4	No-Go
63E	110	52^o					66	No-Go
63W	38	39^o					15	No-Go
64E	150	33^o					42	No-Go
64W	50	75^o					47-1/2	No-Go
65E	2	5^o					0	Go
65W	22	35^o					7	No-Go
66E	70	51^o					40	No-Go
66W	3	90^o					3	No-Go
67E	4	15^o					1/4	Go
67W	1-1/2	90^o	3	15^o			1-3/4	Go
68E	1-1/2	90^o	1-1/2	15^o			1-1/2	Go
68W	15	50^o					10	No-Go
69E	2	90^o	1-1/2	12^o			2	Go
69W	2	90^o	3-1/2	9^o			2	Go
70E	Swamp							
70W	5	90^o					5	No-Go
71E	Swamp							
71W	Swamp							
72E	Swamp							
72W	Swamp							

Site	Data from original field notes h	θ	h	θ	h	θ	Severity factor $s=h(\sin\theta)^2$	Qualitative Evaluation
73E	4-1/2	11°					1/4	Go
73W	Swamp							
74E	Swamp							
74W	Swamp							
75E	Swamp							
75W	Swamp							
76E	Swamp							
76W	Swamp							
77E	Swamp							
77W	6	8°					1/4	Go
78E	Swamp							
78W	5	90°					5	No-Go
79E	17	20°					1-3/4	Go
79W	8	90°					8	No-Go
80E	8	63°					6-1/2	No-Go
80W	6	45°					6-1/2	No-Go
81E	5-1/2	90°					8	No-Go
81W	8-1/2	90°					8-1/2	No-Go
82E	4	70°					7-1/4	No-Go
82W	4	45°					2	No-Go
83E	14	90°					14	No-Go
83W	14	90°					14	No-Go
84E	2-1/2	60°					2	Go
84W	2-1/2	60°					2	Go
85E	12	90°					12	No-Go
85W	10	45°					5	No-Go
86E	3-1/2	90°					3-1/2	Go
86W	1	90°	1-1/2	20°	2-1/2	90°	3-3/4	Go
87E	11	54°					7-1/2	No-Go
87W	9	90°					9	No-Go
88E	3	90°					3	No-Go
88W	3	90°					3	No-Go
89E	10	35°					3-1/4	No-Go
89W	10	40°					4-1/4	No-Go
90E	5	90°					5	No-Go
90W	6.5	90°					6-1/2	No-Go
91E	6	70°					5	No-Go
91W	6	70°					5	No-Go
92E	10	70°					8-3/4	No-Go
92W	10	70°					8-3/4	No-Go

	Data from original field notes						Severity factor	Qualitative
Site	h	θ	h	θ	h	θ	$s=h(\sin\theta)^2$	Evaluation
93E	9	90°					9	No-Go
93W	17-1/2	36°					5-3/4	No-Go
94E	14	50°					8-1/4	No-Go
94W	8	90°					8	No-Go
95E	7	36°					2-1/4	No-Go
95W	6	70°					8-1/4	No-Go
96E	2	90°	5	20°			2-1/2	Go
96W	7	90°	2	20°			7-1/4	No-Go
97E	6	90°					6	No-Go
97W	6	90°					6	No-Go
98E	8	90°					8	No-Go
98W	8	90°					8	No-Go
99E	8-1/2	70°					7-1/2	No-Go
99W	8-1/2	90°					8-1/2	No-Go
100E	9	90°					9	No-Go
100W	8	90°					8	No-Go
101E	5	35°					1-3/4	Go
101W	5	45°					2-1/2	Go
102E	300	70°					275	No-Go
102W	4	25°					3/4	Go
103E	30	38°					12-1/2	No-Go
103W	33	38°					14-1/2	No-Go
106E	18	40°					7	No-Go
106W	100	54°					67-1/2	No-Go
107E	9	70°					8	No-Go
107W	2	90°	14	64°			13	No-Go
108E	20	15°	50	80°			50	No-Go
108W	20	40°					7-1/2	No-Go
109E	10	54°					6-3/4	No-Go
109W	10	18°	70	50°			41-1/4	No-Go
110E	27	11°					1	Go
110W	8	90°					8	No-Go
111E	Buildings							
111W	Buildings							
112E	25	60°					20	No-Go
112W	14	16°	18	90°			19	No-Go
113E	9	10°					1/4	Go
113W	10	90°					10	No-Go
114E	5	30°					1-1/4	Go

	Data from original field notes						Severity factor	Qualitative
Site	h	θ	h	θ	h	θ	$s=h(\sin\theta)^2$	Evaluation
114W	36	90°					36	No-Go
115E	7-1/2	90°					7-1/2	Go
115W	2	90°	4	18°			2-1/2	No-Go

TABLE IV

SWAMP FOX II RIVER EXITING TESTS*

		M-113			M-114			M-116		
Exit	S**	Trials	Go	No-Go	Trials	Go	No-Go	Trials	Go	No-Go
1	4-1/2	7		7	5		5	2		2
2	3/4	1	1		1	1				
3	4	5	1	4	3		3	3		3
5	3/4	4	4		4	4				

* Reference 2.

** Geometric severity factor computed by $s = h (\sin \theta)^2$

TABLE V

ANALYSIS OF
M-113 RIVER EXITING PERFORMANCE
USING THE GEOMETRIC SEVERITY FACTOR

HURON RIVER

	Data from original field notes														Severity	
Site*	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	Factor**	M-113***
16R	2.5	35													3/4	Go
16L	1.5	5	1.75	20	5	15									1/2	Go
17R	1.5	30	3	5	5	15									3/4	Go
17L	3	40	1.5	10											1 1/4	Go
18R	5	20	1.5	10											1/2	Go
18L	3.5	75	2	35											4	Marginal
19R	3.5	10	3	10											0	Go
19L	1.25	10	2	30	3.5	10									1/2	Go
20R	2.25	10	2	25											1/4	Go
20L	1.5	45	5	15											1	Go
21R	1	40	2.5	10	1.25	60									1 1/2	Go
21L	5.75	5													0	Go
22R	2	15													1/4	Go
22L	1.5	10	4.75	40											2	Go
23R	18	45													9	No-Go
23L	3	15													1/4	Go
24R	1.25	90	1.25	60	14	20									3 3/4	Marginal
24L	1	30	2	10											1/4	Go
25R	2	20													1/4	Go
25L	1	90	1	10	2	10									1	Go

* L and R refer to left and right banks when looking up stream.

** Values to nearest 1/4.

*** Based on severity factor groupings of 0-2: GO, 2-4: Marginal, and 4+: NO-GO

HURON RIVER
(continued)

Site	Data from original field notes h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	Severity Factor	M-113
26R	3	15													1/4	Go
26L	1	45	1	15	4.5	5	3.5	20							1	Go
27R	3.5	5	1	10	1.5	5									0	Go
27L	2.5	5	1.5	45	5	10									1	Go
28R	1	10	1	45											1/2	Go
28L	2	10	1.5	45	1.5	10	2.5	5							3/4	Go
29R	1	5	1.5	35											1/2	Go
29L	1	15	3.5	45	2	15	2.5	5							2	Go
30R	1	30													1/4	Go
30L	1	90													1	Go
31R	2	20	4.5	75	14	20									6	No-Go
31L	5	10	1.5	5											1/4	Go
32R	2.75	5													0	Go
32L	1.5	90													1 1/2	Go
33R	3.5	5	3	35	3	10									1	Go
33L	4	5	3.5	10	1.5	90	1	15							1 1/2	Go
34R	3.5	35	9.5	15	5	45									4 1/4	No-Go
34L	2	60													1 1/2	Go
35R	2.5	35	2.5	10											3/4	Go
35L	4	20													1/2	Go
36R	11.5	20													1 1/4	Go
36L	6.5	20													3/4	Go
37R	1.5	40	1.5	10	6.5	25									2 1/4	Marginal
37L	7	25	2	5											1 1/4	Go
38R	1.5	10	10	20											1 1/4	Go
38L	1	15	9	20											1	Go
39R	10	20													1 1/4	Go
39L	85	30													2 3/4	Marginal

HURON RIVER
(continued)

Site	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	Severity Factor	M-113
	Data from original field notes															
40R	8	40													3 1/4	Marginal
40L	7	60	10	35											8 1/2	No-Go
41R	9.5	30	9	5											2 1/2	Marginal
41L	11.5	10													1/4	Go
42R	3	10	4.5	25	3	10									3/4	Go
42L	3	5	2	15	13.5	30									3 1/2	Marginal
43R	2	5	2	10	3	20	9	60	10	10					7	No-Go
43L	3.5	5	1.5	10	9	60									7 1/4	No-Go
44R	1.5	20	8	45											4 1/4	No-Go
44L	1.5	45	4	90	5.5	25	3.5	15							6	No-Go
45R	4.5	35	1	5	2	20									1 3/4	Go
45L	1.5	10	1	35	2	75	2.5	25	5	75					6 3/4	No-Go
46R	4	20	4	35	4	15									2 1/4	Marginal
46L	1.5	5	3.5	15											1/4	Go
47R	7.5	20	4	10											1	Go
47L	3	5	5	15											1/4	Go
48R	4	25	3	20	1.5	10	1.5	20							1 1/4	Go
48L	2	10	5	75											4 3/4	No-Go
49R	1	10	3	20	4	5									1/4	Go
49L	2	20	5	60	3.5	30									5	No-Go
50R	1.5	20	5.5	20	4	10									1	Go
50L	2.5	15													1/4	Go
51R	1.5	10	4	25	3	60	6	30							4 1/2	No-Go
51L	2	5	3	20											1/4	Go
52R	3	20	8	40	4.5	5	13.5	20							4 3/4	No-Go
52L	3.5	5	5	45	1.5	20									2 3/4	Marginal
53R	4	10	3.5	75											3 1/4	Marginal

HURON RIVER
(continued)

Site	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	Severity Factor	M-113
	Data from original field notes															
53L	2	15	1	45	1.5	90	3	40	3.5	75					6 1/2	No-Go
54R	4	5	1.5	45	2	10	5	45							5 3/4	No-Go
54L	8	20	6.5	90											7 1/2	No-Go
55R	4	20	5	30											1 3/4	Go
55L	2.5	15	1.5	20	1.5	90	3	25	3.5	20					3	Marginal
56R	11	15													3/4	Go
56L	2	5	3	25	4	15									3/4	Go
57R	3.5	90	1	20											3 1/4	Marginal
57L	4.5	15	6	30											1 3/4	Go
58R	1	10	5.5	45	1.5	10	2.5	25							3 3/4	Marginal
58L	2.5	5	1	15	2	90	9	35							5	No-Go
59R	1.5	25	8.5	90											8 3/4	No-Go
59L	4	10	1	5	9	30									2 1/4	Marginal
60R	1.5	15	10	90											10	No-Go
60L	5	15	2.5	15											3/4	Go
61R	5.5	75	9.5	25											7	No-Go
61L	15	30													3 1/2	Marginal
62R	9	25	5	15											1 3/4	Go
62L															0	Go
63R	12	30													3	Marginal
63L	5	5	4	15											1/4	Go
64R	10.5	30	7.5	20											3 1/2	Marginal
64L	2	10	1.5	25	6	5									1/4	Go
65R	9.5	20													1 3/4	Go
65L	4.5	5	5	25	5	60	10	20							5 1/2	No-Go
66R	2	10	9.5	30											2 1/2	Marginal
66L	2.5	90	2.5	30	4	45	9.5	30							7 3/4	No-Go

HURON RIVER
(continued)

Site	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	Severity Factor	M-113
	Data from original field notes															
67R	10	30													2 1/2	Marginal
67L	7	25													1 1/4	Go
68R	10	40	1.5	10											1 1/4	Go
68L	9.5	20													1 3/4	Go
69R	3	5	6	90											6	No-Go
69L	3	10	7	25	2	10									1 1/4	Go
70R	1.5	5	7	60											5 1/4	No-Go
70L	5.5	25	14	15											2	Go
71R	2	20	1	90	1	10	1.5	15	2.5	10	10	35			4 1/2	No-Go
71L	2	15	1.5	90	1	5	3	15	1	10	2.5	10			2 1/4	Marginal
72R	2.5	5	6.5	35	5	25									3 1/4	Marginal
72L	2.5	5	4	60	4	10									3	Marginal
73R	3.5	15	1	5	6	10									1/2	Go
73L	7.5	20													1	Go
74R															0	Go
74L	3	15	2.5	20											1/2	Go
75R															0	Go
75L	3	20													1/4	Go
76R	2.5	20	2.5	5	5	15	1	5	4.5	30					1 3/4	Go
76L	2	5	1	15	2.5	5									0	Go
77R	8	5	1	90	30	60									22 1/2	No-Go
77L	2.5	5	2.5	20	4	75									4	Marginal
78R	3	5	5	15	1.5	90	5	35	5	10	9	20			4 3/4	No-Go
78L	3	5	3.5	25	2	10	4.5	90							5 1/4	No-Go
79R	3.5	5	5	30	1.5	90	2	10	6	30	3.5	10	5	25	5 1/4	No-Go
79L	2.5	5	5	15	4	90									4 1/4	No-Go

HURON RIVER
(continued)

Site	Data from original field notes														Severity Factor	M-113
	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ		
80R	3	10	5	25	1.5	90	2.5	10	6	15	9.5	20			3 1/2	**Marginal**
80L	3.5	5	5	15	4	90									4 1/4	**No-Go**
81R	1.5	5	10	45	12.5	30									3	**Marginal**
81L	1.5	25	5	20	7	10									1	**Go**
82R	1.5	15	8.5	60	4.5	15	10	60							14 1/4	**No-Go**
82L	1.5	25	4.5	60	5	20	3.5	10	4	25					4 3/4	**No-Go**

TABLE VI

ANALYSIS OF
M-113 RIVER EXITING PERFORMANCE
USING THE GEOMETRIC SEVERITY FACTOR

BLACK RIVER

	Data from original field notes														Severity	
Site*	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	Factor**	M-113***
1R	.5	23	3.25	45	2	6									1 3/4	Go
1L	1.25	5	.75	8	2	25	6	60	1.5	X	4	20.5			5 1/4	No-Go
2R	1.0	5	1.5	15			3	10							0	Go
2L	1.5	5	2	45	1.5	15	1.5	5	1.5	25					1 1/4	Go
3R	2.5	5	3.5	45	3	15	4	30							3	Marginal
3L	1.25	5	2.5	90	2.5	15									2 3/4	Marginal
4R	1	35	2.5	60	2	5	15	20							3 3/4	Marginal
4L	5.5	20	3	14											1	Go
5R	1	15	2	20	2.5	5									1/4	Go
5L	2	10	4	20	4	5									1/2	Go
6R	1.75	5	1.5	45	3	20	7.5	10	4.5	20					1 3/4	Go
6L	16.5	15													1	Go
7R	1	25	1	90	2.25	45	2	15	2.75	15	6	45	2	15	5 1/2	No-Go
7L	3.5	10	2.5	7											0	Go
8R	2	45	5	15	4	45	3.5	10							3 1/4	Marginal
8L	4.5	30													1 1/4	Go
9R	1.75	60	5	15	4.5	35									3	Marginal
9L	3.5	5	2.5	10											0	Go
10R	3	5													0	Go
10L	2.75	5	6.5	15	10	20									1 3/4	Go

* L and R refer to left and right banks when looking up stream.

** Values to nearest 1/4.

*** Based on severity factor grouping of 0-2: GO, 2-4: Marginal, and 4+: NO-GO.

BLACK RIVER
(continued)

Site	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	h	θ	Severity Factor	M-113
	Data from original field notes															
11R	3	5	3	35	2.5	10									1	Go
11L	1.5	10	3	75	3.5	15	17.5	25							6	No-Go
12R	1	10	2	10	2	5									0	Go
12L	2.5	15	3.5	75	5	40									5 1/2	No-Go
13R	2	5	1.5	10	4.5	20									1/2	Go
13L	4	10	3	40	3.5	7									1 1/4	Go
14R	3.25	5	2	45	2.5	10									1	Go
14L	2.5	25	3	60	2.5	5									2 3/4	Marginal
15R	1	5	1.5	20	7.5	35	3.5	25							4	Marginal
15L	3	30	6	10											1	Go

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13. ABSTRACT

A previous study of river magnitude and frequency established river exiting as the primary problem for vehicles attempting to cross rivers. Analysis of the exiting problem indicated that the single most important parameter to be considered was the geometric form of the river bank. Evaluation of the probability of an M-113 exiting at each bank surveyed in the magnitude and frequency study was made by relating vehicle performance characteristics to bank descriptions; a determination of the probability of the vehicle exiting was then made on a GO or NO-GO basis. Since much of the environment was extremely severe with respect to M-113 capabilities, this evaluation was fairly straight forward. A numerical method, using a geometric severity to classify bank geometry, was then developed to permit a performance analysis to be conducted on a rational basis.

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
VEHICLE EXITING PERFORMANCE						
RIVER BANK GEOMETRY						
GEOMETRIC SEVERITY FACTOR						
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